GOMEX08 - High Frequency Acoustic Propagation over the Alabama Alps

R. L. Field, P. C. Gallacher, D. A. Hebert and E. Jarosz
Naval Research Laboratory, Stennis Space Center, Mississippi.

***Abstract*- The objective of this work is to diagnose high frequency acoustic propagation directly from oceanographic data and ocean models. To achieve this objective a joint acoustic and oceanographic experiment was performed in the Gulf of Mexico in the summer of 2008. This paper will show that high frequency acoustic propagation at 17.5 kHz tracks the estimated turbulent dissipation rate obtained from field measurements and that ocean modeling gives reasonable estimates of both the turbulent dissipation rate and sound speed. The ocean model sound speed structure is used in an acoustic model to simulate the measured acoustic fluctuations at 17.5 kHz over a four hour period.**

I. INTRODUCTION

The objectives of this work are to experimentally determine if oceanographic estimates of the turbulent dissipation rate (ε) obtained from ADCPs could diagnose high frequency acoustic propagation and to determine if the NRL-MIT Nonhydrostatic Ocean Model will give reasonable predictions of the measured estimates of ε and sound speed structure. The turbulent dissipation rates (ε) were evaluated from the measured vertical shear $\left(\partial u/\partial z\right)$ in velocity using:

$$\varepsilon = 7.5\nu\overline{\left(\frac{\partial u}{\partial z}\right)^2}$$

where ν is the kinematic viscosity of seawater and the overbar denotes depth averaging. Using ε as a diagnostic for high frequency acoustic performance is motivated by Dilorio and Farmer [1]. In that work a path-averaged turbulent dissipation rate (TDR) is estimated from acoustic scintillation analysis. The work here measures and models ε to determine the best and worst times for sending and receiving high frequency acoustic signals and uses the sound speed structure from the ocean model as input to an acoustic model (FEPE, [2]) to predict the acoustic fluctuations in transmission loss.

II. EXPERIMENT AREA, GEOMETRY AND GENERAL PROPAGATION CONDITIONS

From June 29 through July 11 2008 a joint acoustic and oceanographic experiment was performed in the Alabama Alps region of the Gulf of Mexico. The Alabama Alps is part of a group of reef-like structures collectively known as the Pinnacles. In particular, the Alabama Alps rises to about 15-17m above a relatively flat sea floor of 90m depth. Depending on the nature of the flow, turbulent wakes periodically form in the vicinity of these structures. Fig. 1 shows the general area of the Pinnacles and the specific Alabama Alps experimental site of this paper. The Alabama Alps region (Fig. 1, lower left) was chosen for its simplicity as compared with the Scamp Reef region (Fig. 1, upper right). The experimental geometry at the Alps is overlaid on the bathymetry shown in Fig. 2. The orange plus symbols labeled ACDS2 and ACDS3 (Acoustic Communication and Data Storage buoys) are the acoustic transceivers. Each consists of a broadband transducer and an 8-channel vertical receiving array. The acoustic data that is shown here was transmitted by ACDS2 located to the east of the Alps and received at ACDS3 located west of the Alps. The acoustic source depth on ACDS2 is 55m and the top and bottom hydrophones on ACDS3 are at 46 and 60m, respectively. The hydrophone separation is approximately 2m. The range between the two ACDS buoys is 3238m. The red dots labeled T/C moorings are vertical arrays of temperature and conductivity sensors. The purple dots labeled BARNY moorings are the three ADCPs from which current speed and ε are estimated.

The Alabama Alps region was an area of extensive oceanographic measurements prior to this experiment. The year before this experiment was conducted a pilot study was conducted to obtain bathymetry and sound speed so that acoustic modeling could be done for experimental planning. One of the major concerns was how best to deploy the acoustic transceivers so that the acoustic propagation was through the turbulent zones and did not scatter or reflect off the Alps itself. This would add significant complication to the data analysis. The sound speeds estimated from the temperature and salinity measurements made the year before indicated a strongly downward refracting acoustic environment as is evidenced by the transmission loss simulation at 17.5 kHz shown in Fig. 3. Since the acoustic transmission is downward refracting, placing the source and receiver equidistant from the Alps makes the dominate paths skip over the Alps and enveloping the area where the dominate turbulence is expected to occur. The zones of convergence occur approximately at the source depth of 55m. The vertical bar denotes the 8-channel vertical receiving array.

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14. ABSTRACT
The objective of this work is to diagnose high frequency acoustic propagation directly from oceanographic data and ocean models. To achieve this objective a joint acoustic and oceanographic experiment was performed in the Gulf of Mexico in the summer of 2008. This paper will show that high frequency acoustic propagation at 17.5 kHz tracks the estimated turbulent dissipation rate obtained from field measurements and that ocean modeling gives reasonable estimates of both the turbulent dissipation rate and sound speed. The ocean model sound speed structure is used in an acoustic model to simulate the measured acoustic fluctuations at 17.5 kHz over a four hour period.

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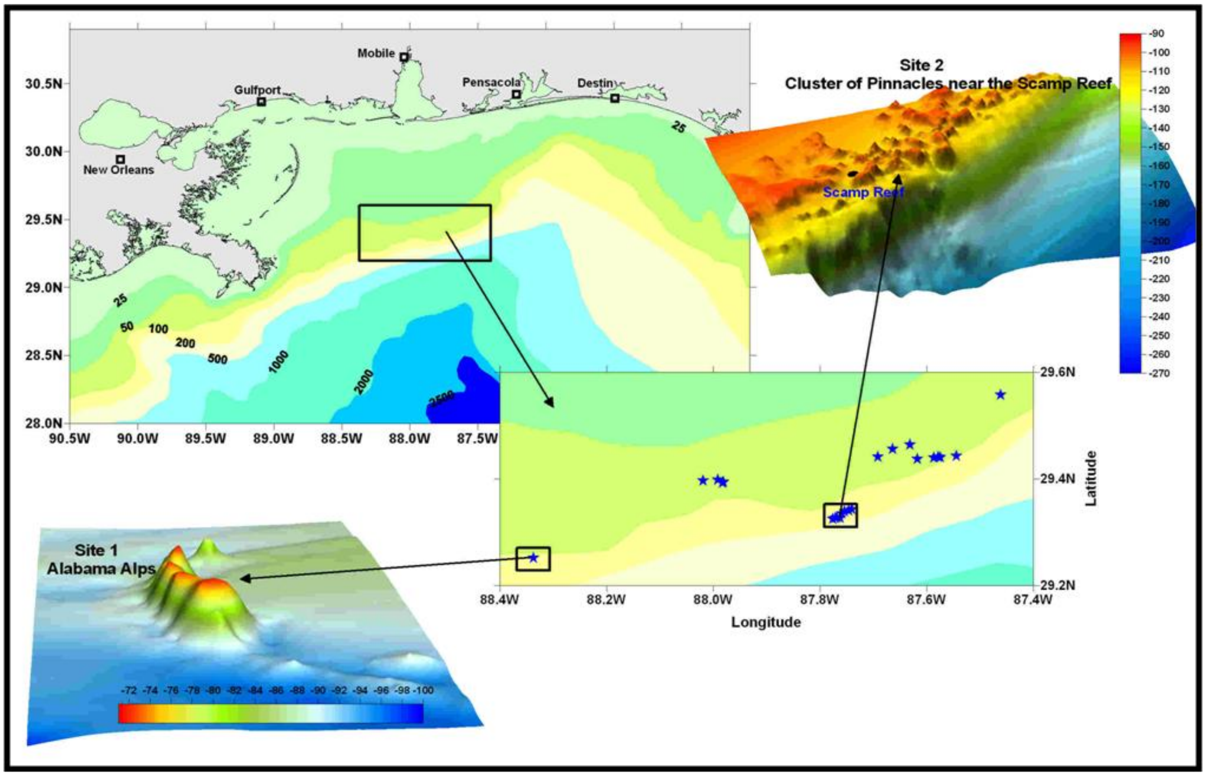

Fig. 1. Experimental area off the coast of Mississippi and Alabama

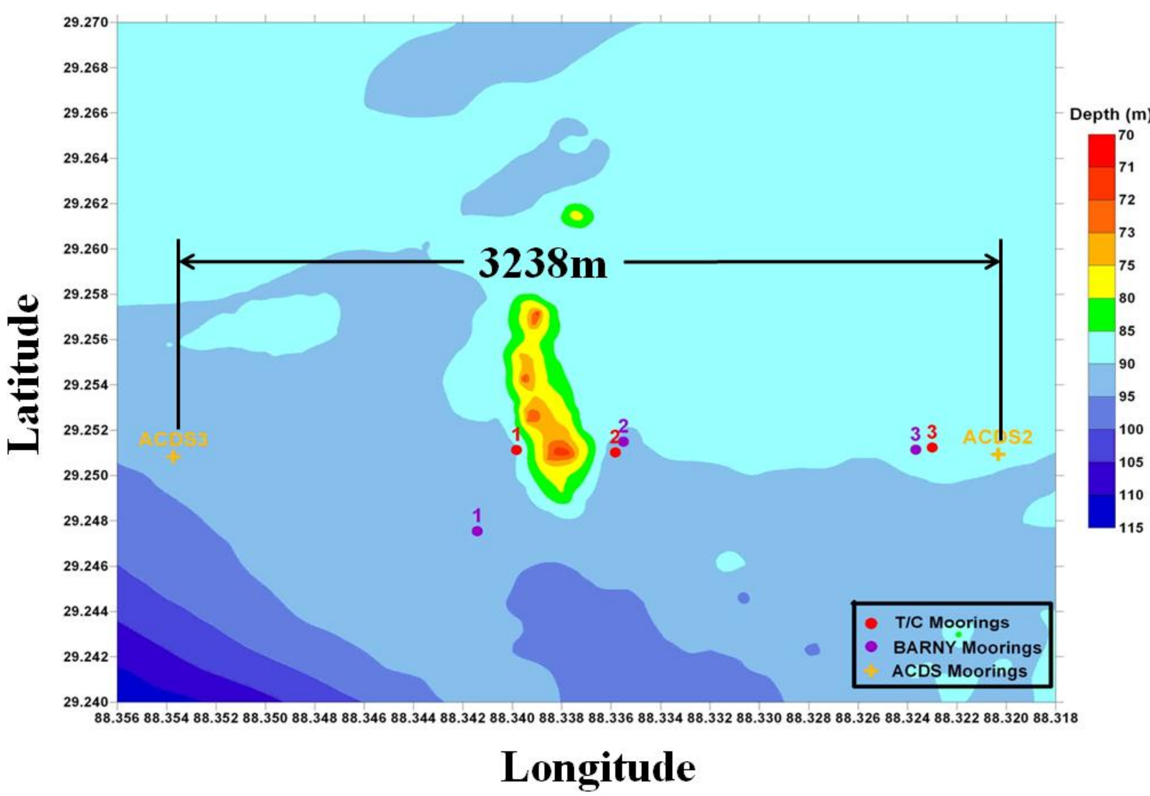

Fig. 2. Experimental geometry at the Alabama Alps

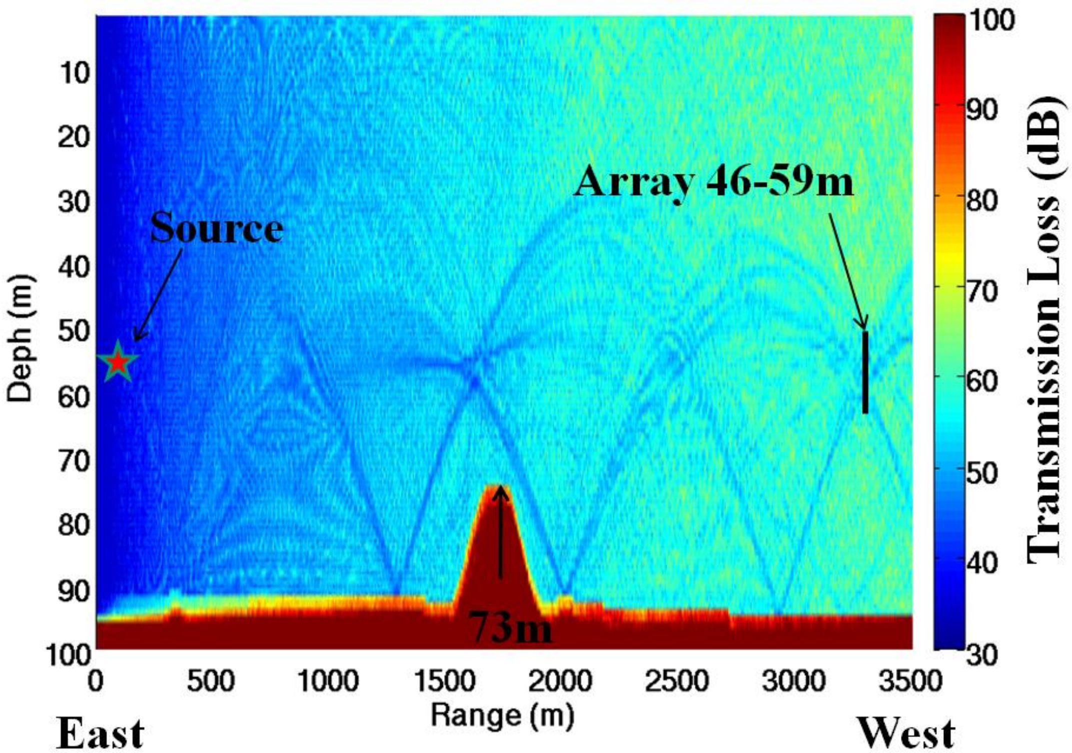

Fig. 3. Transmission loss simulation with sound speeds measured the year before the experiment. The frequency is 17.5 kHz, source-receiver range is 3238m

The Alps rise 15-17m above a relatively flat bottom as is shown by the vertical arrow. The dominate flow direction during the experiment was westward. Therefore, the acoustic propagation that will be shown is in the direction of the dominate flow. Another simulation was done after the experiment with sound speeds measured at the site. The sound speed structure showed the same downward refracting character giving almost the same simulation results.

III. CURRENT SPEED AND TURBULENT DISSIPATION RATE AT THE THREE ADCP LOCATIONS

The magnitude of the current for the 24-hour period during which the acoustic propagation took place is shown in Fig. 4 at each of the ADCP locations (labeled as BARNY moorings in Fig. 2). The current measurements were taken over a 7 day period and display a 24-hour oscillation that is due to both inertial oscillations and a diurnal tide. The current has been depth averaged over 46 to 60 meters, the same depth interval as the vertical array aperture. The mean current measured by ADCP is approximately 10 cm/s. The bursts with speeds to 20-25cm/s at ADCP 2 gives rise to high ε shown in Fig. 5. The figure shows that at all three ADCPs ε begins to increase by orders of magnitude beginning at about day 184.95 and starts to drop off around day 185.45. Because ADCP2 (black line) is on the acoustic propagation path (BARNY mooring 2, Fig. 2), this ε estimate will be weighed more than ADCP1 or ADCP3. If the sound speeds estimated from T/C moorings 1, 2 and 3 (Fig. 2 red) are averaged over these same depths there is no consistency in their trends and the changes in sound speed are 1m/s or less. For example, ε at ADCP2 changes from -62 dB on day 184.95 to -40 dB on day 185.0, a change of 22 dB over .05 days (1.2 hours). The sound speed change over the same time interval is .5 m/s or less at T/C moorings 1, 2 or 3. In this case, the inconsistency and the small magnitude of the changes make sound speed a less robust metric of acoustic propagation performance than ε.

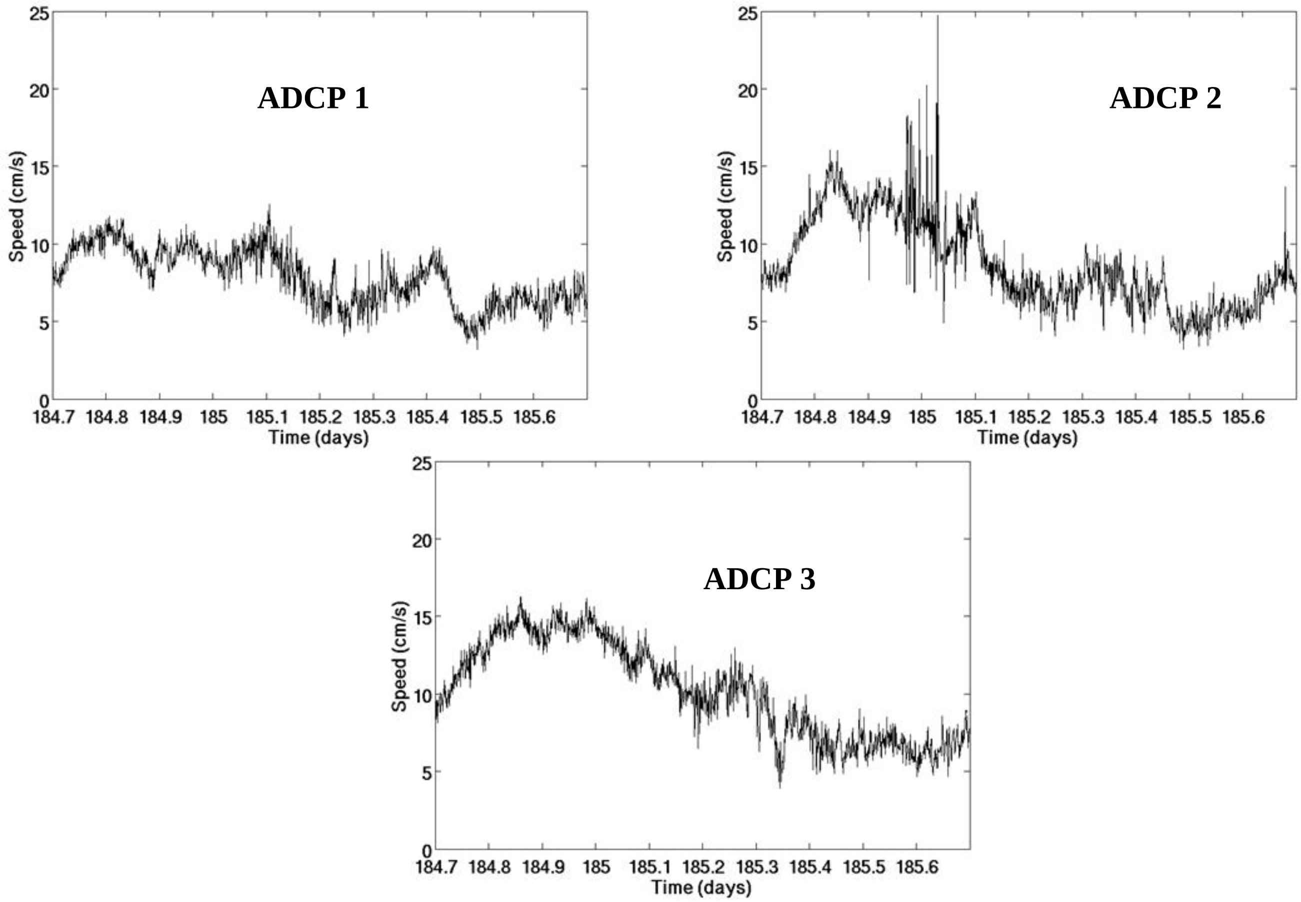

Fig. 4. Depth averaged current at ADCP locations 1, 2 and 3.

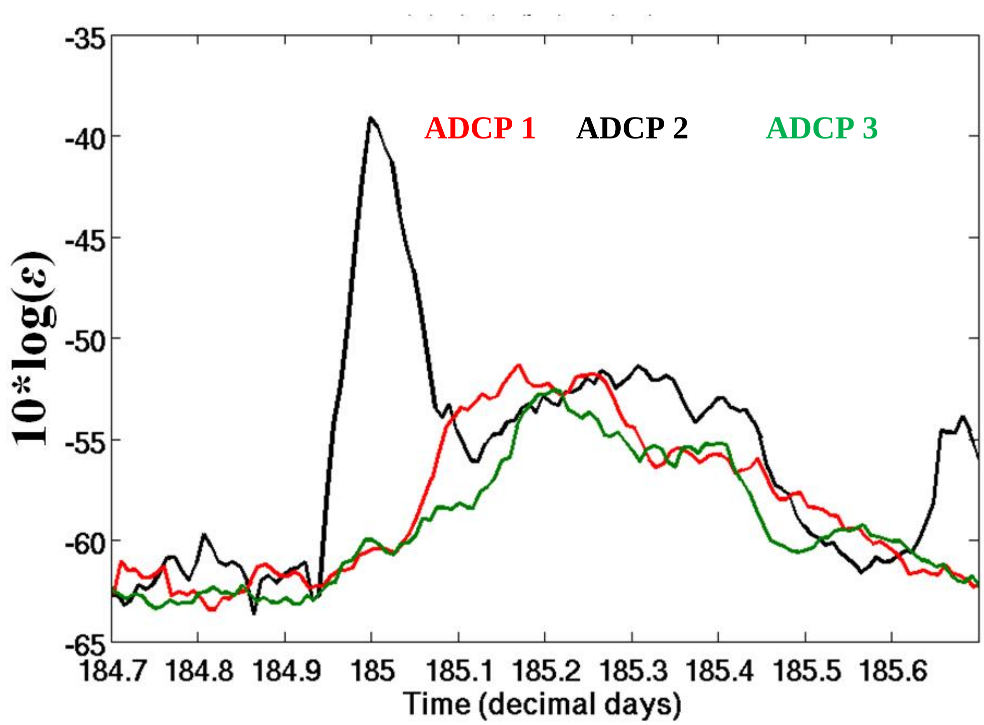

Fig. 5. Log of the depth averaged turbulent dissipation rates ε as a function of time estimated from ADCP 1 (red), ADCP 2 (black) and ADCP 3 (green).

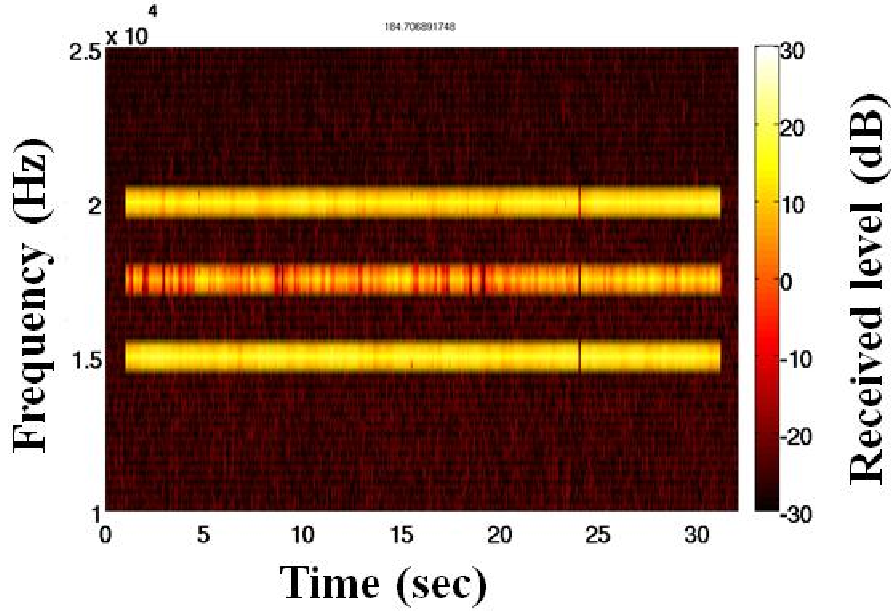

Fig. 6. Time-frequency display of a single channel reception of a 15, 17.5 and 20 kHz comb.

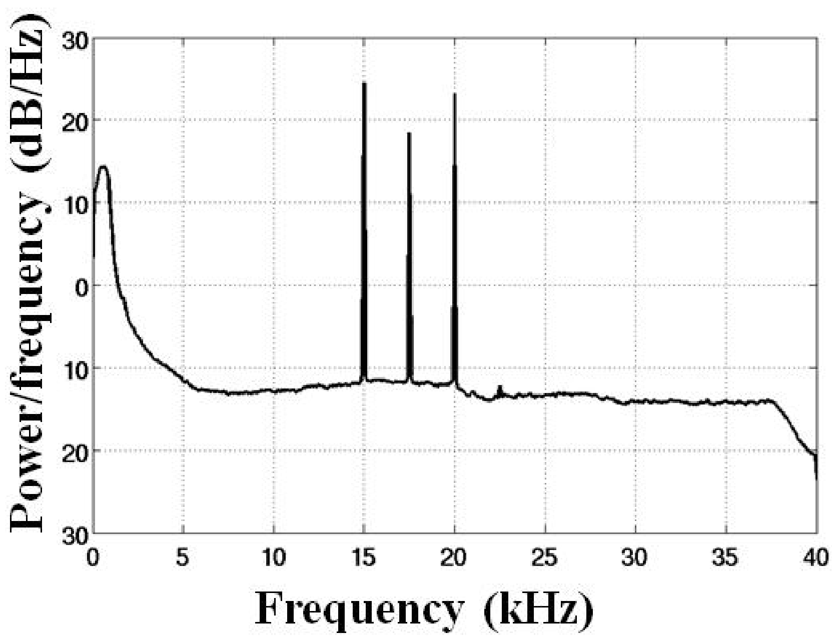

Fig. 7. Power spectral density estimate of comb shown in Fig. 6.

IV. ACOUSTIC POWER SPECTRAL DENSITY TIME SERIES AT 17.5 KHZ

Fig. 6 shows one of the signals transmitted during the experiment. Displayed is a comb of three frequencies, 15, 17.5 and 20kHz, received on one of the eight channels of ACDS3 (Fig. 2 orange plus to the west of the Alps). The comb was transmitted every 5 minutes from ACDS2 (Fig. 2 orange plus to the east of the Alps) at a depth of 55 meters and a range of 3238 meters. The power spectral density (PSD) was estimated using Welch's method with a 1024 point window with no overlap. The sampling rate was 80000 samples/sec. The PSD estimate for the comb shown in Fig. 6 is plotted in Fig. 7, where a signal-to-noise ratio of over 25 dB for all three frequencies can be seen. This was a typical reception during the 24-hour transmission. Power spectral densities were computed for each channel every five minutes over a 24-hour time period and averaged over all eight channels to form a PSD time series.

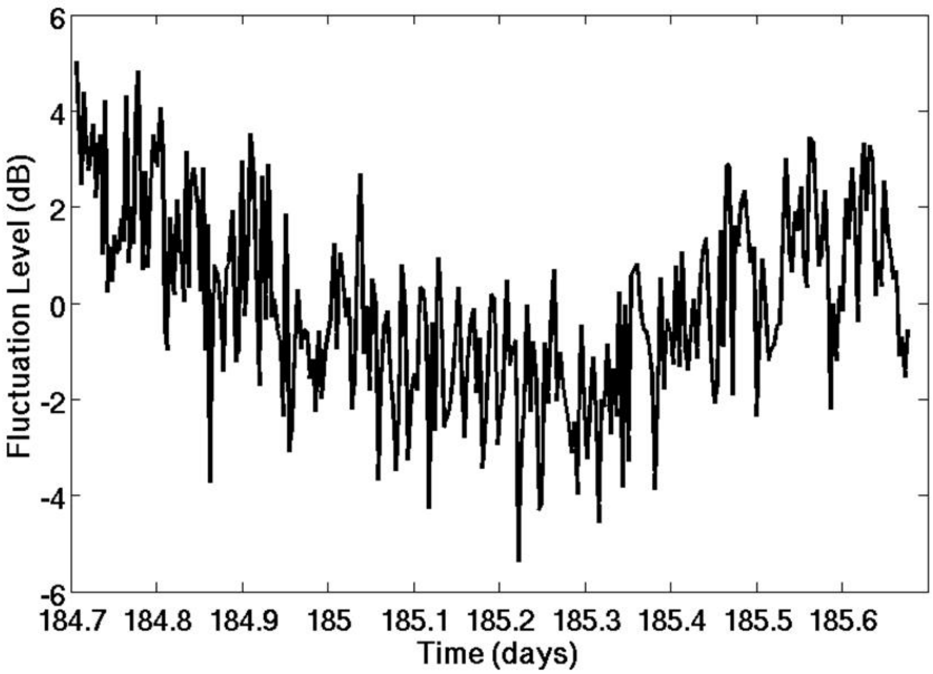

Fig. 8. Power spectral density (PSD) time series at 17.5 kHz with the averaged removed.

Fig. 8 shows the depth averaged PSD time series at 17.5 kHz over a 24-hour period with the averaged removed. This is labeled as “fluctuation level” in the plot. The fluctuation character of the time series changes to higher frequency starting around day 185. This is better observed by smoothing the time series of Fig. 8 over a period of one hour. Fig. 9 shows the smoothed time series, at the top, and the ε from ADCP1, 2 and 3, displayed previously in Fig. 5, are shown at the bottom for comparison.

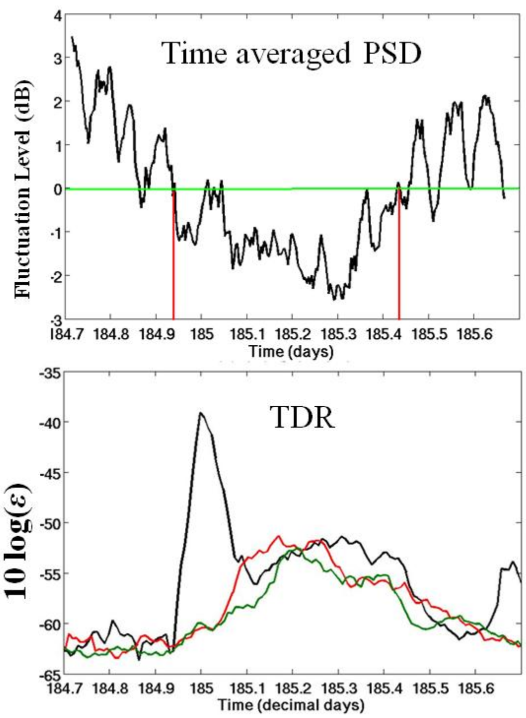

Fig. 9. Top figure: smoothed PSD time series. Bottom figure: turbulent dissipation rates shown if Fig. 5 for comparison.

The green line at the top of Fig. 9 is the zero mean level. The two red vertical lines indicate the times where the fluctuation dips below the average received level. The two red lines are at day 184.95 and 185.45. These are the times where ε begins to increase and decrease, respectively, by orders of magnitude. At about day 185.05 to approximately 185.45 the fluctuation amplitude decreases and the frequency of the fluctuation increases. Before 185.05 and after 185.45 the fluctuations have relatively constant amplitudes and a dominant frequency. Due to a lack of space, the broadband analysis cannot be shown here. It shows that the acoustic PSD time series should be delayed by .04 days (1 hour). Shifting the PSD time series by this amount (about .5 scale division on the plot) aligns the PSD at 185.05 with the main peak of ε at day 185 on ADCP 2 (bottom of Fig. 9, black). The time delay of one hour is consistent with an internal wave forming at the Alps at a range of 1619m from the receiving array, ACDS3, and traveling at a speed of 46 cm/s. Oceanographic analysis of the internal waves over the Alps estimates the speed to be between 40 and 50 cm/s. This indicates that ε is a reasonable metric for high frequency acoustic propagation performance.

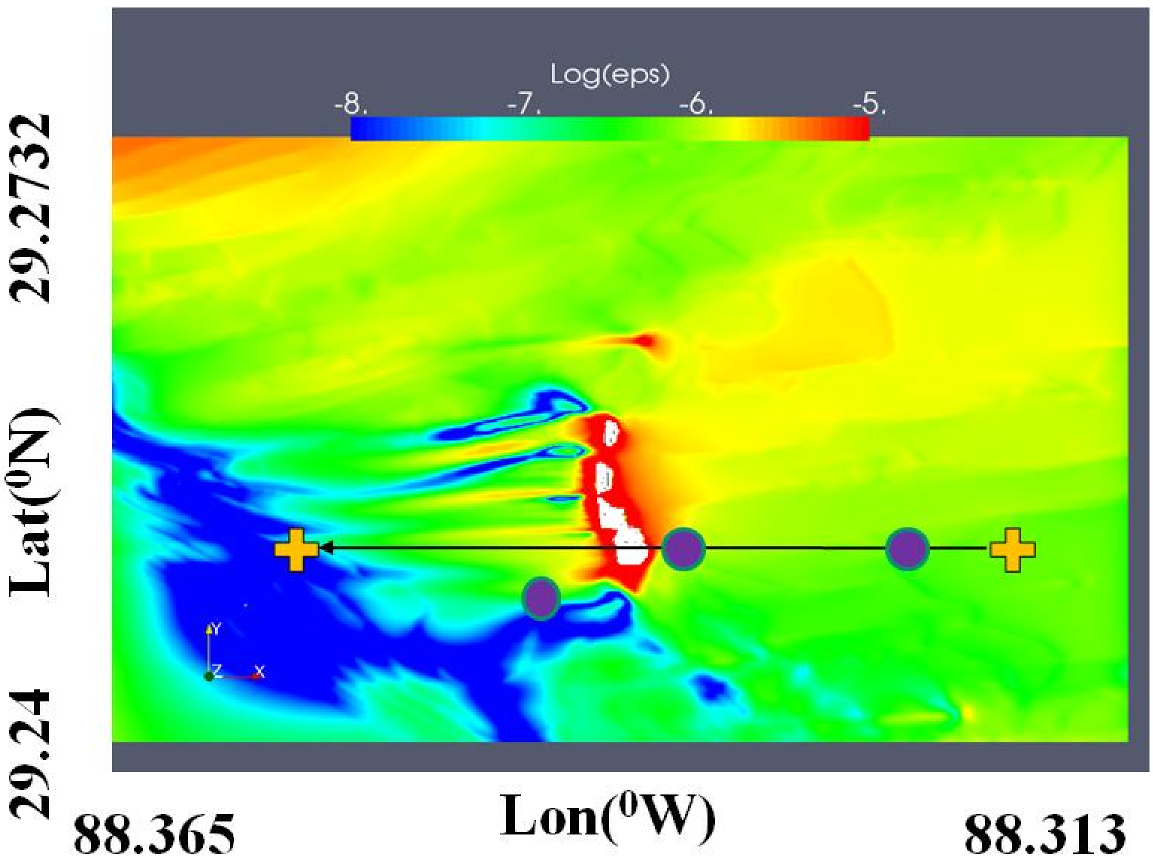

Fig. 10. Turbulent dissipation rates computed from the NRL-MIT Nonhydrostatic Ocean Model. Latitude-longitude view.

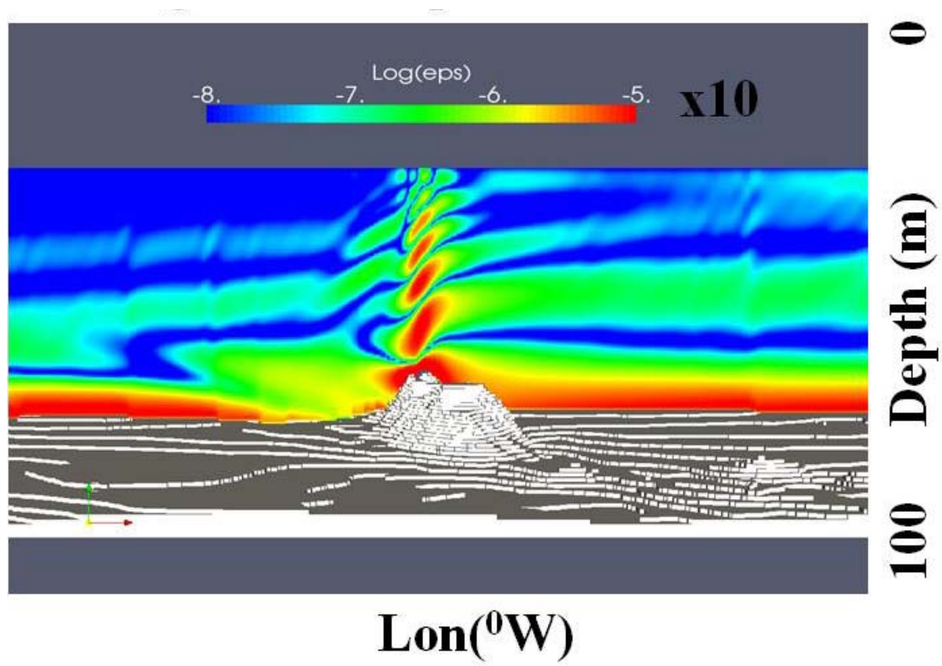

Fig. 11. Turbulent dissipation rates computed from the NRL-MIT Nonhydrostatic Ocean Model. Longitude-Depth view.

V. TDR AND SOUND SPEED PREDICTIONS FROM THE NRL-MIT NONHYDROSTATIC OCEAN MODEL

As mentioned in Section II, there was considerable oceanographic data available from the Alabama Alps area before the experiment took place. Temperature, salinity, density and buoyancy frequency profiles were taken at 12 stations around the Alps. A smoothed average of the profiles was used as the initial conditions for the model. The forcing used was a 10 cm/s barotropic westward current. The 10 cm/s flow corresponds to the mean flow observed on ADCPs 1, 2 and 3. The simulations shown do not include a variable 24-hour forcing due to inertial oscillations and the diurnal tide. Fig.10 shows a latitude-longitude view of the Alabama Alps with the experimental assets overlaid. The orange plus to the east of the Alps (right) is the acoustic source and the orange plus to the west (left) is the acoustic receiving array. The purple dots are the ADCPs from which the ε estimates are made as a function of depth and time. With this simple initialization of the model, the ε's shown in Fig. 10 are consistent with the measured estimates shown in Fig. 5 prior to day 184.95. If the mean flow is 10 cm/s, the ε corresponding to this should represent the background ε. At the ADCP locations shown in the Figure 10, 10log(ε) ranges between -50 and -65 m^2/s^2. Fig. 11 shows a longitude-depth view of ε in the immediate vicinity of the Alps. For a forcing speed of 10 cm/s, the flow is hydraulically controlled and a hydraulic jump forms over the Alps as shown by the high ε values. The flow becomes supercritical with respect to the Froude number when the flow is greater than 10 cm/s. Therefore, for speeds 10 cm/s or greater, kinetic energy of the flow should dissipate into turbulent wakes and high frequency internal waves. The high ε estimated at ADCP 2 at day 185 (Fig. 5, black) due to the burst of speed to 20-25 cm/s (Fig. 4, ADCP 2) is consistent with the hypothesis that the change in the character seen in the PSD at the top of Fig. 9 is due to an internal wave forming at the Alps.

The ocean model sound speeds were validated by doing a time dependent transmission loss simulation at 17.5 kHz. The simulation was performed over a four hour period that corresponded to a statistically stable ocean state for the 10 cm/s flow. To compare with the acoustic fluctuations shown at the top of Fig. 9, the temporally smoothed fluctuations were high-passed filtered in order to remove the 24-hour period due to the inertial oscillations and the diurnal tide. The 24-hour high-passed time series and the 4-hour simulation are shown in Fig. 12. The simulation is depth averaged over the same depth interval as the acoustic array (46-60 meters). No temporal smoothing was done. The simulation (red) was arbitrarily shifted to line up with the first peak. The agreement is good with respect to the amplitude of the fluctuation and its period during times that correspond to the background ε.

VI. CONCLUSIONS

In conclusion, ε can be used to diagnose high frequency acoustic propagation performance. The NRL-MIT Nonhydrostatic Ocean Model, using a simple initialization from climatological temperature and salinity profiles as well as a barotropic forcing of 10 cm/s, gives ε values comparable to those estimated from ADCP measurements and sound speeds that predict reasonable fluctuation levels and periods at 17.5 kHz.

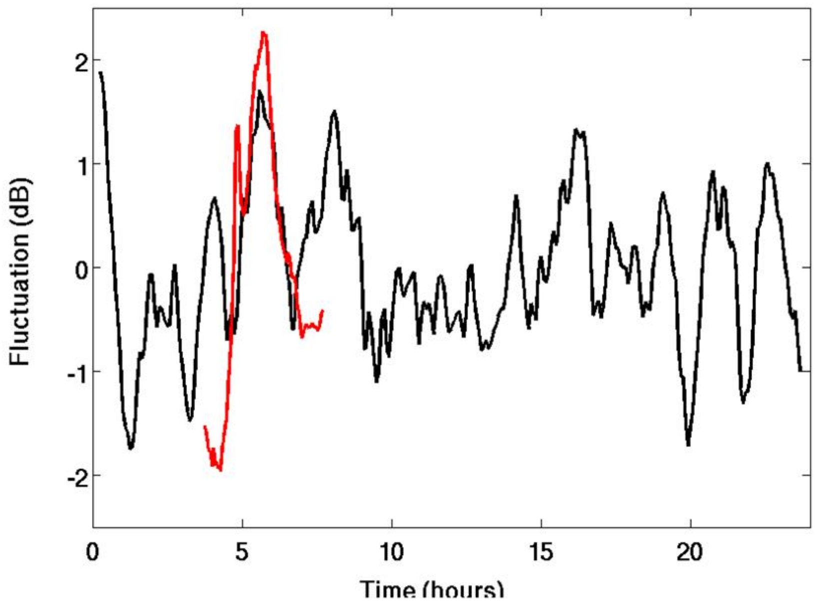

Fig. 12. The high-passed filtered acoustic fluctuation time series over 24 hours (black) at 17.5 kHz and the 4-hour acoustic model simulation (red).

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